

# The DUNE Near Detector DAQ Case for Support

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## 1 Introduction

The long-baseline neutrino facility (LBNF) will be the world's most intense high-energy neutrino beam (up to 2.4 MW). It will fire neutrinos 1,300 km from Illinois towards the 70,000 ton Deep Underground Neutrino Experiment (DUNE) detector in South Dakota in order to study neutrino oscillations. LBNF/DUNE is being built in the USA and has been identified as a very high science priority both by the US and by the UK. It will undertake a game-changing programme of neutrino physics aiming to answer major scientific questions on the origin and structure of the universe. The neutrino beam is sampled by two detectors, a near detector located onsite at Fermilab, and a far detector in the SURF facility in South Dakota.

The near detector will measure parameters of the beam and neutrino interactions before the neutrinos have oscillated that are critical to achieving the required precision in the oscillation measurements with the far detector. It is crucial to the success of the experiment; without it, the science reach in oscillation physics is greatly diminished. The near detector also provides the capability for exotic physics searches and measurements of neutrino cross sections with unprecedented precision. Involvement in the near detector was identified by the DUNE Project Board and the Particle Physics Review Panel as having the highest priority for further UK involvement on DUNE based on the high impact on the physics programme and potential for UK leadership.

The DUNE near detector concept is detailed in a conceptual design report. Briefly, it consists of a pixelated liquid argon TPC (LArTPC) with a fast light timing system, backed by a high pressure gaseous TPC (HPgTPC), which is surrounded by a plastic scintillator calorimeter. These three detectors, as a unit, are movable from on-axis in the neutrino beam, up to 20 m off-axis, allowing a range of neutrino beam energies to be measured with the detectors; this allows the detector to resolve effects coming from the neutrino flux from effects coming from neutrino cross sections. A separate detector suite consisting of a 3D segmented plastic scintillator detector with a magnetic spectrometer sits downstream of the HPgTPC when the detectors are run in on-axis mode, and remains on-axis to monitor beam stability when the other detectors are moved into off-axis positions. In total, this results in at least six subsystems.

## 2 Objectives

The primary objective of this proposal is to deliver the DUNE Near Detector (ND) Data Acquisition (DAQ) system in the context of the overall DUNE DAQ technology. This project has several intermediate and related sub-objectives as follows:

- Develop a readout unit suitable for data rates of order 100 MB/s
- Develop the trigger and data selection for near detector physics
- Implement a DUNE timing system for the near detector
- Develop the appropriate control, configuration, and monitoring systems
- Deliver an intermediate DAQ system for the DUNE ND Liquid Argon Factory

### 3 Project Description

The DUNE ND has three primary detector components and the capability for two of those components to move off the beam axis. The three detector components serve important individual and overlapping functions with regard to the mission of the ND. Because these components have standalone features, the DUNE ND is often discussed as a suite or complex of detectors and capabilities. The power in the DUNE ND concept lies in the collective set of capabilities and the complementary information provided by the components. A drawing of the DUNE ND in the ND hall is shown in Figure 1.

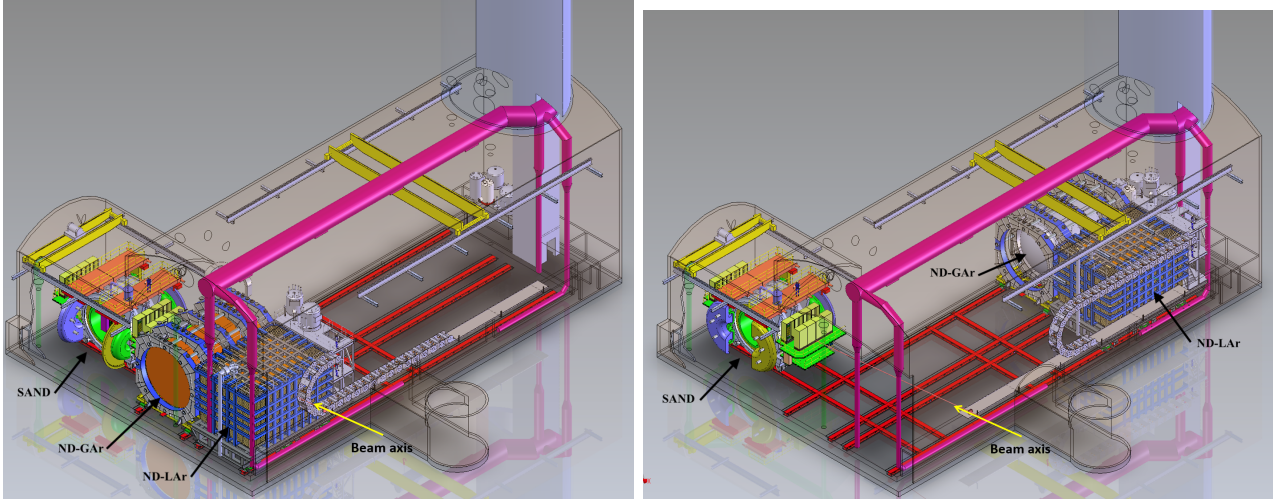


Figure 1: Schematic of the DUNE ND hall shown with component detectors all in the on-axis configuration (left) and with the ND-LAr and ND-GAr in an off-axis configuration (right). The SAND detector is shown in position on the beam axis. The beam axis and direction is indicated.

The first component of the DUNE ND is a liquid argon time projection chamber (LArTPC), called ND-LAr. This detector has the same target nucleus and uses the same fundamental detection principles as the DUNE FD, but has an increased position resolution using pixelated charge readout due to the expected intensity of the beam at the ND. The use of the same target nucleus and a similar technology reduces sensitivity to nuclear effects and detector-driven systematic uncertainties in the extraction of the oscillation signal at the FD. ND-LAr also has a light readout system using silicon photomultipliers (SiPMs), and may potentially add a upstream veto system, also using SiPMs.

ND-LAr begins to lose acceptance for muons above  $\approx 0.7$  GeV/c due to lack of containment. Because the muon momentum and charge are critical components of the neutrino energy determination, a magnetic spectrometer is needed downstream of ND-LAr to measure both quantities. In the DUNE ND concept, this function is accomplished by the ND-GAr detector. The ND-GAr detector consists of a high pressure gaseous argon TPC surrounded by an electromagnetic calorimeter (ECAL) in a 0.5 T magnetic field with a muon system outside of that. The high pressure gaseous argon TPC (HPgTPC) runs at 10 atmospheres and provides a lower-density medium with excellent tracking resolution to momentum analyze the muons from ND-LAr and act as an independent argon target. The HPgTPC is readout through a pixelated charge readout, similar to ND-LAr, and the ECAL and muon systems will be readout using SiPMs. Depending on available resources, this part of the detector may be installed as an upgrade, and before its installation, a temporary muon spectrometer may be installed; this technology will use plastic scintillator coupled to SiPMs.

ND-LAr and ND-GAr can move to take data in positions off the beam axis. This capability is referred to as the DUNE Precision Reaction-Independent Spectrum Measurement (DUNE-PRISM). As the detectors move off-axis, generally together, the incident neutrino flux spectrum changes, with the mean energy dropping and the spectrum becoming narrower. The data taken at different off-axis angles will allow the deconvolution of the neutrino flux and interaction cross section, as well as the mapping of the reconstructed versus true energy response of the detector. However, the beam must be continually monitored in the on-axis position to ensure that the beam parameters do not change.

The final component of the DUNE ND suite is a magnetized beam monitor called the System for on-Axis Neutrino Detection (SAND). This device monitors the flux of neutrinos going to the FD from an on-axis position where it is much more sensitive to variations in the neutrino beam. SAND consists of an inner tracker surrounded by an ECAL inside a large solenoidal magnet. Currently two options are being explored for the inner tracker, one based on a combination of plastic scintillator cubes with SiPMs and one based on straw-tubes. The magnet and ECAL are repurposed from the KLOE detector, which is a cylindrical collider detector previously used to study  $\phi$  meson production at the INFN LNF laboratory in Frascati, Italy. It has a superconducting coil that provides a  $\approx 0.6$  T magnetic field and an excellent lead-scintillator ECAL.

Altogether, the near detector has at least six and as many as nine detector subsystems that must be readout through a data acquisition system. The detector subsystems are summarized in table ??.

Detector	Subdetector	Status
ND-LAr	Charge Readout	Confirmed
	Light Readout	Confirmed
	Upstream Veto	Unconfirmed
ND-GAr	cell2	cell3
	cell5	cell6
	cell8	cell9
SAND	cell2	cell3
	cell5	cell6
	cell8	cell9

- Description of DUNE DAQ
- Description of how the two meet

### 3.1 Readout Units

Lower data rates at the ND mean that the planned readout unit for the DUNE FD is substantially over-specified for the needs of the ND. This section of work is aimed at specifying the hardware for, developing the software for, and procuring and installing readout units suitable for the ND and integrated with the overall DUNE DAQ system.

This system is based on commercial, off-the-shelf servers with custom software developed by the project team. The system is required to accept data from a variety of front end electronics (FEEs) on the various detector subsystems, buffer the data for a specified time, and, when requested, pass the data to the overall DAQ data flow system in order to be built into events. The deliverables for this work are:

- Understand the requirements from the ND subdetectors which drive specifications of COTS units
- Design and write the software that handles data input, storage, and output
- Test and verify sample electronics from ND subdetectors before detector installation
- Provide prototype readout units to ND subdetector test stands and ND LAr Factory

This work begins in 2022 with the design and prototype of a readout unit for an ND-LAr test stand. The DUNE DAQ has developed a ‘miniDAQ’ app that performs a stripped-down version of DAQ functions, with an intended use for test stands and prototypes. This early work will build on this app by integrating communication with existing ND-LAr electronics for both the charge and light systems. As both communicate via standard protocols, it will be possible to deliver a prototype by Sept 2022.

In 2023, experience with the prototype system will drive necessary changes, as well as understanding the requirements for the units to be delivered for the production line of the ND-LAr system, as well as supporting the delivery and integration of the system.

Over the next two years (2024 and 2025), the effort on this project focuses on ensuring that all of the FEEs that use the ND readout units integrate correctly with the system, and providing a test bed for detector groups to test versions of their electronics. This will ensure that that installation of the final system is smooth. There will be further development of the readout unit software for the integration of the FEEs and to keep pace with the development of the overall DAQ software.

At the end of 2025, the final hardware specification will be determined, based on the experience of the prototypes and test stands and a refined understanding of expected data rates from detector subsystems.

Staff

- PD
- WPV
- PDRA 1

### 3.2 Data Selection

As the DUNE ND has different technologies and physics from DUNE FD, the data selection strategies must be customized for the ND. This section of work is aimed at developing these data selection algorithms and strategies.

The DUNE ND must collect data from beam-induced events, controlled calibration events, and uncontrolled calibration events. Of these, the most important for DUNE physics are beam-induced events which can be determined by timing with information from the accelerator complex. Controlled calibration events are calibration events generated by external hardware, e.g., LED light generated to calibration SiPMs. Uncontrolled calibration events are calibration events generated from natural processes, such as cosmic rays or radioactive decays.

Most of the FEE for detector subsystems are expected to zero-suppress the signals being transmitted to the DAQ, which substantially reduces the data selection burden for the system. However, it is expected that allowable data volumes for permanent storage will mean that the amount of data coming from the detectors must be reduced. The detector consortia are currently engaged in a process of determining the physics requirements for data taking, so the overall scale of reduction is not yet known. It is likely that it will be around 1–2 orders of magnitude. This means that this work must be flexible to engage with both the detector consortia and the computing consortium in order to achieve the requirements led by both.

Once the requirements are specified, the strategies to achieve this reduction can be determined. Typical strategies for this process include pre-scaling (e.g., only recording a fraction of uncontrolled calibration events), physics triggering (e.g., algorithms that look for interesting energy deposits localized in certain parts of the detector), time slicing (e.g., recording a window of time and accepting what comes within it), and data aggregation (e.g., reducing the total information written to permanent storage from certain parts of the detector).

The key tasks for this work are:

- Determine the scale of data reduction required by the system
- With the detector consortia, develop data prioritization requirements
- Develop a data selection system for prototype test stands
- Develop a data selections strategy for beam events
- Develop a data selection strategy for controlled and uncontrolled calibration events
- Ensure the data selection system runs to the required speed
- Specify and procure the hardware which will run the data selection system

This work begins in 2022 with development of data selection for prototype detectors and test stands, with a particular focus on ND-LAr. This work may be able to both contribute to and draw from work being done for ProtoDUNE-II, which has similar requirements to both the prototypes and the final ND. At the same time, the final physics requirements for the ND will be established.

From here, there is uncertainty on the required effort for the remaining tasks.

- 2022–2023 Develop test stand needs
- 2024–2025 Develop algorithms
- 2026–2027 Develop algorithms

Staff

- JH
- KD
- PDRA 2

### **3.3 Delivery of ND timing system**

- 2022–2023 Decision on Single Phase Timing System or White Rabbit
- 2024–2025
- 2026–2027

Staff

- LC
- QMUL FLF PDRA
- technical staff?

### **3.4 Contribution to overall DAQ core software**

- 2022–2023 CCM
- 2024–2025 CCM
- 2026–2027 CCM
- PDRA 3
- MOW

### **3.5 Test stands and prototype detectors**

A critical part of the development of the DAQ will be to support prototype detectors and test stands across the ND detectors, which allows the detector consortia to experiment with and validate electronics design and to become familiar with the functioning of the DAQ system before the installation of the final detector. This work will be done in close collaboration with the detector consortia. The overall DAQ consortium is in the process of constructing and releasing a 'miniDAQ' app that is designed to support test stands, and this package of work will rely on this effort, customized for the needs of the ND subsystems.

This project currently plans to support the following prototypes and test stands:

- A ND-LAr prototype, likely at Fermilab (2022)
- A FEE development test stand at Imperial College London (2022)
- The ND-LAr module factory at Fermilab (2024)
- An HPgTPC test stand at Fermilab (2024)
- A FEE validation test stand at Fermilab (2025)

It is anticipated that other subdetector systems may desire prototype support as well, but have not yet progressed sufficiently to determine location or time scale.

To support these test stands, the miniDAQ app must be customized for the ND FEE. This work is synergistic with the Readout Unit work, as the miniDAQ is designed such that software can be written for the miniDAQ app and translated directly to the full DAQ framework with no to minimal changes. This allows concepts to be tested in these test stands before inclusion in the full DAQ. In 2022, the effort for developing the readout unit and supporting the ND-LAr prototype is nearly identical for this reason.

Additionally, in 2022, a test stand will be set up for FEE development at Imperial College London. ICL is involved in developing the HPgTPC FEE, and the stand will allow for rapid prototype development. It will also allow other subdetectors to visit with their FEE concepts to us for testing and integration evaluation as they design their boards. In the early part of the project, it is useful to have this setup in the UK. This also allows the project to train subdetector experts on using the DAQ and develop the knowledge base for them to support their own test stands in the future.

- 2022–2023 Factory development, FEE stand, ND LAr prototypes?
- 2024–2025 FEE testing, MPD/SAND/other prototypes
- 2026–2027 Final FEE testing (wind down)

Staff

- PD
- ICL FLF PDRA
- PDRA 1

#### **Asher draft**

A description of the applicants proposed contribution to the project should be given. The stage of the project (e.g. R&D, construction etc.) should be specified. The document should highlight any unique contributions, likely global impact and aspects of UK leadership.

## **4 STFC Science and strategy**

**Jon**

Identify the specific STFC science opportunities that this project addresses. How does this relate to STFC priorities? What aspects are particularly relevant? What is its potential impact? Are there any long-term implications or liabilities that may be generated as a result of investing in this project?

- STFC Science priorities and neutrino physics
- This project brings additional leadership for the near detector with complete intellectual ownership of the readout and data selection for the near detector as a whole unit.
- bridges between the detectors and the physics
- addresses a specific need for the international collaboration that enhances the UK reputation

## 5 Awareness & Context

### Morgan

Describe the present status of related research and development worldwide. Where is this research field likely to be in 10 years' time? What is the current state of play? How important is it that we act now? Does the project have a strong supportive user base among the relevant community both in the UK and internationally?

## 6 Competing research

Within the DUNE project, there are no other groups competing to take ownership of this package of work. The contribution of this UK group is viewed as a positive, welcome contribution to the ND effort and the overall project.

In a global view, there is competition between the DUNE project and the Hyper-Kamiokande project; both projects are pursuing the measurement of CP violation in the neutrino sector. For both experiments, the control of systematic uncertainties with their near detector suites is key to maximizing their sensitivity to this parameter. By delivering a robust and optimal DAQ system, this project will ensure that data from the DUNE ND will be available from the first data taking of DUNE so that the experiment will be able to use this critical data in its race against Hyper-Kamiokande.

## 7 Track record

### all

Explain your track record in this field. Why do you consider your group the best or most appropriate to carry out this programme? How should the introducers be confident that you would be able to deliver the project? What is the competency of your group to perform this work?

## 8 Project Management Plan

We propose to manage this project under the overall DUNE UK Project Management Structure, as described [REFERENCE]. As the DAQ work must be tightly integrated with the FD DAQ work, the aspects of the project related to this will be managed through DUNE WP 2, forming a sub-work package of that overall package, 2.10. *Kaboth* will be the manager of this work package, reporting to Giles Barr and Simon Peeters as the overall DAQ work package managers. This has been agreed with the current DUNE UK leadership.

## 9 Project organisation and participants

### Asher/Jon

Proposals should identify the implementation strategy, duration, project deliverable ownership, and work packages; representation of this information in Gantt chart format is recommended. All funded UK participants, their staff category, FtE (full time equivalent) project/work package allocation per year, activity and justification for each post, should be listed. Key individuals, such as the UK Spokesperson and Project Manager(s), responsible for ensuring that the project and its constituent parts are kept on schedule and budget should be identified.